Collaboration Technologies for Global Manufacturing

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Abstract

One impact of the globalization of manufacturing is the growing requirement for teams that are not co-located to collaborate using shared information. In this paper, we present our approach to instituting and assessing collaboration technologies for manufacturing applications. We provide a brief overview of Computer Supported Cooperative Work (CSCW) and groupware and discuss some potential uses in manufacturing. We describe related research at NIST, focusing on a process engineering collaboration scenario. We also present two approaches to collaboration technology deployment, *seeding* and *accelerated deployment*, aimed at reducing deployment costs in the manufacturing environment. Ultimately, the work presented here, in addition to similar systematic deployment and assessment of collaboration tools in other manufacturing scenarios, will provide knowledge that is useful for manufacturers who wish to efficiently deploy and effectively use collaboration technologies.

Introduction

The increasing globalization of manufacturing and distribution of enterprises demands concurrent information exchange and collaboration throughout the product development life cycle. This creates an increasing dependence on information technology to share disparate data among geographically dispersed staff. Globalization trends and recent advances in information technology provide an opportunity now for computer supported cooperative work (CSCW) (Menon, 1997). There are many opportunities for CSCW in manufacturing to enable, for example, decision-making, product and process design, and research. Imagine this scenario, where advanced integrated CSCW technology is used to enable the efficient trouble shooting of a manufacturing process problem by one of the few experts available in a highly specialized field:

> Jade is a welding engineer that works for Cars-R-Us. While reading through her e-mail, she notices that her icon for the welding collaboratory[1] starts flashing yellow. She opens up the collaboratory icon, and a popup window informs her that there is a problem in the chassis welding line. Clicking a button takes her to that "room" in the collaboratory.
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> One of the main tools in the room is a dynamically updated data table that lists all the welds and associated weld quality (green, yellow, red) that have been performed on that day for each welding workstation Jade oversees. She sees a long list of good welds with two interspersed that have fallen into the yellow range. (Having a second one fall into the yellow range is what generated the alert on her workstation). Clicking on the data for the first yellow weld, she sees a Virtual Reality Modeling Language (VRML) current-voltage graph plotted over the geometry of the weld. Clicking on a button on that plot causes it to be overlaid with a transparent template for a good weld, with tolerance ranges indicated. She can clearly see that the weld is going bad near the end of the run, and she begins to suspect a part fit-up problem.
>
> She goes to the more recent yellow weld and brings up the VRML plot and overlays it on the good template. Surprisingly, this weld goes bad at the beginning, then corrects itself. Jade clicks on the "playback" button, which brings up a video window with some controls on it. A video of the weld along with audio gets played, and as it plays, a highlight marker on the VRML graph sweeps through the plot in synch with the audio, video, sensor, and weld controller log playbacks. Jade begins to associate some spikes in the graph with some sounds and data she reviewed in the playbacks and begins to form a theory.
>
> She goes back to the weld data table and clicks on a thumbnail image to bring up a snapshot of the finished product (a closeup snapshot is taken by the video camera after each weld is finished). She notices some telltale signs in the weld itself that confirms her theory, and she calls up Harry, the job setter for this welding cell, and asks him to use his PC to join her in the collaboratory room. She points out the features she sees in the data, and works with Harry on what specifically might be causing the problem and how to fix it. It looks like something might be going wrong with the power supply of the work cell.
>
> They decide to call in an electrician to look at it. Jade suggests that Harry show the electrician the current-voltage graph when he arrives to help explain the problem they suspect with the power supply. If there are more questions after the electrician has had a chance to look at the welding power supply, she offers to have them call her back. As they finish up their call, Jade notices a flashing red signal in her collaboratory. Then, she quickly moves on to the problem that has stopped a welding line over in the body assembly area.

[1] "collaboration" + "laboratory"

The basic technology components exist for enabling this and other types of collaboration that will be common in future global manufacturing environments. The challenge is in understanding the collaboration requirements of manufacturers, and identifying and integrating appropriate collaboration technology solutions. In this paper, we focus on the collaboration aspects of geographically dispersed manufacturing systems and the effective use of software to enable collaboration and describe current research at the National Institute of Standards and Technology (NIST). First we provide a brief overview of CSCW and groupware, a description of some potential uses in manufacturing and approaches to accelerate deployment of this technology. Then we will describe related research at NIST, focusing on a process engineering collaboration scenario, and conclude with future research plans.

Background

Computer Supported Cooperative Work Technologies

While computers are familiar tools used by people to pursue individual tasks, the exploitation of computers to assist people working together is in its infancy. Many off-the-shelf applications in general use are "single-user" systems and vary from office applications to finite element and simulation applications. In the last ten to fifteen years, attention has been slowly turning to multi-user systems through *groupware* and *computer supported cooperative work*. *Groupware* is software that supports and augments group work. It is a technical label differentiating "group-oriented" products designed to assist groups of people working together from "single-user" products that help people pursue their isolated tasks. Familiar examples of groupware systems are electronic mail, conferencing systems, group schedulers, group decision support, and whiteboard systems (Greenberg, 1994). "*Computer supported cooperative work* (CSCW) is the scientific discipline that motivates and validates groupware design. It is the study and theory of how people work together, and how the computer and related technologies affect group behavior. CSCW is an umbrella collecting researchers from a variety of specializations—computer science, cognitive science, psychology, sociology, anthropology, ethnography, management, management information systems—each contributing a different perspective and methodology for acquiring knowledge of groups and for suggesting how the group's work could be supported." Because of its multi-disciplinary nature and youth, CSCW is still a forming discipline (Greenberg, 1994).

There are many factors that must be addressed for successful adoption of information technology (IT) systems in general, and groupware[2] systems specifically (Ehrlich, 1987, Wallace, 1997, Goren et al., 1994, Kovavainen et al., 1998]. Six such factors are listed below:

- Sufficient management backing,
- Effective, grassroots user champion(s),
- Group dynamics conducive to cooperative work,
- Corporate mentality conducive to cooperative work,
- Non-threatening technology, especially with respect to job security, and
- Support for users' tasks and processes.

Successful groupware deployment is more than installing video conferencing on every computer workstation available; it is a thoughtful exercise that considers many factors, just as there are many perspectives contributing to the CSCW discipline. Specifically, its aim is to apply the right collaborative tool(s) for a job given many factors. For instance, There is considerable research showing that adding audio to desktop conferencing improves problem solving among team members, however there is no benefit to adding video (Williams, 1997). Meanwhile, new research shows promise for video providing significant benefit when used in tasks involving speakers with different priorities and different linguistic capabilities (Williams, 1997). This type of finding holds the promise to support increasingly diverse work

[2] Groupware, sometimes referred to as collaboration technology, shares many characteristics of information technology (IT) systems.

teams in our increasingly global economy. With the aid of CSCW, groupware will eventually support the way we work, i.e., cooperatively, and often distantly located.

Collaboration Technology for Manufacturing

Groupware is used primarily for communicating, problem solving or troubleshooting, and decision making. These issues concern many activities in manufacturing. As with all types of businesses, manufacturers must make decisions and solve problems in groups, and could benefit from the use of collaboration technology tools that have capabilities such as shared workspace, anonymity, communication channels, meeting leader/facilitator, group memory, and access/concurrence control (dos Santos et al., 1997). There are some specific opportunities for garnering collaboration technology benefits in manufacturing, which, for illustrative purposes, are discussed here.

In the introduction, we described a scenario where collaboration tools are used to troubleshoot a problem with an automated welding process. There are many scenarios repeated throughout process engineering, similar to trouble shooting problem welds, where collaborative tools would be useful. In these scenarios there are problems with a process and there are various types of "experts" including operators and engineers who are not necessarily co-located. They need to communicate regarding the problem, symptoms, past history, etc., and they need to suggest and experiment with alternatives (e.g., using integrated simulation tools, etc.).

Another area that has benefited from some CSCW research is in the "co-engineering" of product designs. Many product designs require multiple engineering disciplines, e.g., electro-mechanical aspects of engine design require both mechanical and electrical engineers. These engineers and reviewers must be able to make design markups, add annotations, and assess cost and process implications among alternatives. Much of this is asynchronous, especially with "round-the-clock engineering" and co-designing with oversees partners. This requires the integration of independent systems and mechanisms to enable communication among engineers. Carmen (1998) addressed the use of collaborative tools to design a part and its manufacturing processes from concept through production using a geographically dispersed team from multiple companies. The Agile Infrastructure for Manufacturing Systems (AIMS) developed for this Defense Advanced Research Projects Agency (DARPA)-funded program required firewall transparency, a single source of product data (an Internet-based Product Data Management (PDM) system), whiteboarding, virtual process standards, "continuous" design reviews, and virtual enterprise cash-flow management. Enabled by collaboration technologies, the virtual team accomplished work independent of individual time constraints, interacted simultaneously with both local and remote team members, matched the medium to the message, and worked productively both synchronously and asynchronously. Compared with similar past designs, they designed the part 3 times faster, the part count was more than 10 times reduced, the design cost was reduced by a factor of 10, and delivered on time.

There are specific decision-making scenarios associated with Enterprise Resource Planning (ERP) that are opportunities for the exploitation of collaboration technologies. These are situations where, as a result of some unique demand, a group must get together quickly to make a decision. For example, there is an emergency rush order from sales: we can make a sale if we can build it by some specific date. Can we do it? Do we have the resources (materials, people, and equipment)? What is the impact to other orders? Can we live with that? Some of the necessary information to answer these important questions is available in databases, often it is in people's heads, but answers must come quickly to get the sale.

And finally, a huge opportunity to realize the substantial benefits from collaboration technologies arises with the formation and implementation of manufacturing supply chains, where speed and flexibility in communication will be one competitive edge needed to succeed. Many software vendors are developing collaborative tools and citing successful implementation stories, yet as observed by Institute of Electrical and Electronics Engineers (IEEE) Internet Computer, "Many core aspects of business, such as manufacturing, have remained largely impervious to advances in computing technology."[3] The research described in the remainder of this paper attempts to identify and assess collaboration tools and deployment methods specifically for manufacturing in order to support their use for U. S. industry.

Reducing Costs of Effective Implementation

Expense is one major impediment to adoption of information technology in general, and collaboration technology, specifically, in manufacturing environments. There are several types of expense. There are the initial expenses of deployment, the potential expense of failed deployment of ineffective tools, and the expense of unanticipated changes due to the use of these tools. We propose that one way to reduce all of these expenses is to deploy tools in a similar collaboration scenario where deployment expenses are much lower, and then use the knowledge gained from that experience to decrease the time, unknowns, and expenses of deployment in the more expensive environment. This method would likely have an *accelerated deployment* effect of useful tools for manufacturers. In our work with trouble shooting automated welding processes, described later in the paper, we expect that using the knowledge gained from implementing effective CSCW tools in a research environment will reduce the time and expense of implementing effective CSCW tools in a related industrial operations environment. We also expect that using the knowledge gained from understanding the processes in each environment will help make it possible to seed the tool set in each environment with appropriate artifacts. We claim this *seeding* method[4] has several notable consequences. Initially, it will help us determine if a tool can meet the users' requirements in their real world situations. This will lessen the likelihood of a failed deployment due to inadequate tool capability. Secondly, to do the seeding, the workflow and processes must be understood and documented prior to deployment. This has several benefits. IT training staff can use the process documentation to help users learn how to use the tools in their real world situations, thus reducing self-instruction requirements, an adoption barrier. Also, understanding the current work processes will give insights into how the manufacturing processes will change with the introduction of CSCW systems and tools, which is essential for estimating and coping with that change. It should be noted that most major firms do not have their primary workflow and processes documented (Favela et al., 1994). Tackling this for the affected processes will have the previously mentioned positive results. Additionally, this step is needed to turn an artifact-based firm into a process-based one (Conklin, 1992), paving the way for future real corporate-wide knowledge capture and use (Favela et al., 1994), as the capture of process information is ultimately more useful and important than the capture of artifact details for corporations.

Collaboration Technologies for Manufacturing Process Engineering and Trouble shooting

Designing a Collaboratory to Support Automated Gas-Metal Arc Welding

Researchers at NIST's Manufacturing Engineering Laboratory (MEL) and Information Technology Laboratory (ITL) are in the process of instituting and assessing collaboration technologies for manufacturing applications (Steves et al., 1999). We are particularly interested in how collaboration tools can be used in manufacturing environments and how manufacturing practices will change as a result of their use. We expect these studies will yield useful insights into future data interchange standards needs, as well as advance the state of the art and practice in CSCW deployment for the manufacturing domain. Additionally, we are interested in using, developing, and testing methods for reducing the time needed to do effective user-centered design and field studies of groupware systems in manufacturing operations environments where the costs are high for deploying information technology systems. User-centered design has been shown to increase the likelihood of acceptance, effectiveness, and user satisfaction of IT systems (Marcus et al., 1991, Landauer, 1995, Nielsen, 1993). Field studies will be used to document the

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[3] http://www.computer.org/internet/edcal.htm

[4] Some work for supporting the development of design environments (Fischer et al., 1994) has analogous aspects to our seeding method, however, the methods differ in intent, deployment method, application domain, and anticipated outcomes.

work and show where there are changes in manufacturing processes and data exchange requirements as a result of these systems' use.

Our current work, set in the context of automated gas-metal robotic welding, assesses the deployment and use of collaboration technologies for process engineering and trouble shooting. In industry, there is a relative scarcity of welding engineers. This scarcity is due in part to the current requirement that welding engineers be on-site when setting up new welding processes or when trouble arises on a manufacturing welding line. Within a manufacturing site, a welding engineer may need to oversee several different welding lines, which are not physically collocated. Some small, remote welding sites may not have a welding engineer on-site except as absolutely required, usually resulting in downtime while an engineer travels to the remote site to trouble shoot problems. Production lost to travel between locations is a significant cost, especially considering that the typical situation is that engineers are often responsible for more than one site. Other workers are also responsible for welding cells, but generally welding engineers are the scarcest resource. Our research is based on the premise that by using collaboration technology, some, if not substantial, increases in productivity can be achieved. Collaboration is a vital component surrounding the testing and trouble shooting of automated robotic gas-metal welding equipment, welding processes, and the analysis of subsequent welds by a welding team. Collaboration technology holds the promise of realizing substantial savings in productivity by allowing geographically dispersed welding teams to trouble shoot bad welds over time and distance, [5] as conceptualized in the "Jade" illustration.

NIST welding researchers have a similar collaboration scenario, where, as a geographically dispersed team, they are working to define interface standards between welding work cell components, controllers, and power supplies. To achieve this, a functioning welding testbed has been implemented for testing the interfaces between components, controllers, and power supplies. Analysis of welds is performed to verify effective operation of interfaces, equipment, and controllers (Rippey et al., 1997). A geographically dispersed team of people is performing this research and effective collaboration over welding data over time and distance is a critical component to its success. Just as in the industrial operations scenario, task appropriate collaborative and data visualization technologies hold the promise of effective collaboration over time and distance.

To address these issues we have developed a two-phased approach. In Phase I, the welding research environment is targeted. We gather and analyze user requirements, document the process by which the work is achieved, and deploy and evaluate an appropriate set of groupware tools. In Phase II, a welding operations environment, in conjunction with our industrial partners, is the target. Similarly, we gather and analyze user requirements, document the work process, and deploy and assess an appropriate set of tools. The research environment is the "lower cost" environment, as described in the *accelerated deployment* model in the "Reducing Costs of Effective Implementation" section of this paper, i.e., the weld quality analysis (research) activity is quite similar to the welding trouble shooting activity in the operations environment. Table 1 shows the progression of events, the iterative nature of user-centered design, and our progress to-date. The darker shaded cells indicate completed subtasks, the lighter shaded cells indicate in-progress subtasks, and unshaded cells indicate subtasks to be performed in the future. The remainder of this paper describes the results to-date and our future plans.

[5] These ideas were presented and greeted with unanimous support at the National Advanced Manufacturing Testbed (NAMT) Gas-Metal Arc Welding Workshop, September 1998.

Table 1: Process analysis and trouble shooting scenario research phases and progress

TASK	SEQUENTIAL TIME												
Phase I - Research Environment													
Gather & analyze user requirement	x												
Document process		x										x	
Deploy tools & perform user training			x										
Analyze tool use				x			x			x			
Gather & analyze modified/new user requirements					x			x			x		
Deploy modified/new tools & perform user training						x			x				
Assess impact of deployed tools(s)													x
Phase II - Operations Environment													
Gather & analyze user requirement	x												
Document process		x										x	
Deploy tools & perform user training			x										
Analyze tool use				x			x			x			
Gather & analyze modified/new user requirements					x			x			x		
Deploy modified/new tools & perform user training						x			x				
Assess impact of deployed tools(s)													x

User Requirements and Analysis

To collect our users' requirements, we interviewed all of the participants in the research scenario—our starting point—noting their roles and requirements, and one representative industry partner. The latter was included in this early stage as a sanity check of sorts, to keep the focus on a scenario that would translate well to the industry sector. The requirements gathering activity involved the users shown in Table 2.

Table 2: Research Scenario – Users

Role	Location
Manager, test, and experiment coordinators	Gaithersburg, MD
Welding expert	Boulder, CO
Sensor expert	Gaithersburg, MD
Automation experts, cell programmer, simulation expert	Gaithersburg, MD
Product expert (Industry partner)	mid-west U. S.

We determined the following common requirements based on our user interviews.

1. NIST welding experiments have participants in distant locations and time zones, who must collaborate.
    - Welding expertise resides in Boulder, CO.
    - Sensor, automation, and management expertise and the welding workcell resides in Gaithersburg, MD.
    - Welding experiments require interaction among all experts.

2. NIST researchers want to incorporate involvement with industry partners as external users of the welding testbed, where:
    - Industry partners contribute parts for welding experiments.
    - All participants review analysis of experiments.
    - Potentially, external users remotely "weld" using the testbed.

3. The welding process generates a lot of data in various formats that multiple people need to access and review. Collaborative analysis of weld quality requires a shared view of the data by potentially all the participants while discussing together and/or annotating.
        - Raw sensor and controller data is in ASCII (American Standard Code for Information Interchange) format.
        - Visualizations, plots, graphs, and analyses of data are in ASCII, VRML, and future unspecified formats.
        - Photos of finished welds are in GIF (Graphics Interchange Format) and JPEG (Joint Photographic Experts Group) formats.
        - Formats for videos of welds have not been specified, but specifications are expected in the near future.
        - Formats for audio recordings of welds have not been specified. The specification is dependent on required sound quality.

4. NIST researchers require a central repository of data, which has the following characteristics:
    - The repository must support appropriate access permission controls for registered participants (e.g., data submitted by industry partners may need to be protected from other industry partners)
    - The repository must provide a means for organizing data and interactions around a central principle, e.g., around a particular weld or part.
    - The repository must support heterogeneous data formats.
    - The repository must provide user maintenance (additions, modifications, and deletions) of data that is more conducive to use than that for web pages (i.e., avoiding the webmaster bottleneck and the need for a specialized language syntax, such as HyperText Markup Language (HTML)).

5. Synchronous and asynchronous communications are required.
    - Remote expertise may be in different time zones.
    - Capturing interactions has the advantage of documenting them for future reference.
    - There is a need to flexibly move between synchronous and asynchronous interactions.
    - Welding engineer may need to multi-task among several welding problems, e.g.:
        - An engineer may be assigned to one welding plant, but may need to oversee several lines spread out over that plant.
        - Resolving problems in an industry plant may require calling in other appropriate personnel, which takes additional time.
        - Engineers may need to divide time among several problems, and therefore do not want the requirement of being in lockstep synchrony with each current problem.

6. Special networking bandwidth requirements can not be imposed.
   - Some welding industries and sites do not have high capacity networking infrastructure. For instance, the shipbuilding industry has very large welding sites. Because of the size of the work site, it is not effective to have a lot of specialized equipment at just one location. Equipment and their networking connections need to be able to accommodate a large workpiece, potentially by moving around it.

7. Multi-platform computer support is needed for the following platforms[6] (order is not significant): Sun Microsystems, Macintosh, IBM-compatible personal computers, and Silicon Graphics.

8. Potential groupware solutions must be extensible, i.e., the groupware tool(s) must allow for supporting tool integration, such as: specialized welding data visualizations and specialized workflow and/or business process tools.

9. Additional requirements of weld trouble shooting and weld quality analysis activities:
   - Video of welding is useful, but less important than other data including an audio recording of the weld.
   - Video conferencing between people is useful when negotiating which parts to weld.
   - Analysis of welds and trouble shooting interactions will focus largely on shared data.
   - Audio recordings of welds need to be better than phone quality.
   - Weld analysis activity would be helped by data visualization incorporating an overlay of bad welds on a good weld template (for a particular weld) with delineated tolerance ranges.
   - After a weld is completed, a close-up photo or series of photos of the finished weld needs to be captured.
   - To identify trends and analyze problems, a visualization of a time series of good and bad welds per work cell is needed. Further, the database must support this visualization.
   - To support the weld analysis activity, a synchronized replay of weld audio, video, sensor, and controller data is needed. Further, the capability to make annotations at notable events during the weld data replay is especially important.

Gathering user requirements also entailed understanding the pertinent user processes. This activity had a two-fold benefit. First, we better understood user requirements and occasionally were able to ask questions that brought otherwise hidden requirements to light. Second, by understanding the process, we were able to document it, facilitating later identification of process change. For our work, the process includes the major activities shown below, all of which are collaborative with possible occasional exceptions of the "Run experiments" activity:

- Review potential products for use in experiment
- Assess proposed product
- Define experiment
- Run experiments
- Review data

A detailed representation of the users' envisioned process prior to deployment of collaboration tools is included in Appendix A. It includes activities and subactivities, collaboration modes, artifacts of the process, a time scale, and envisioned future process enhancements.

[6] Certain commercial products are identified in this document for the purpose of documenting the evaluation of a class of collaboration technologies. This identification does not imply any recommendation or endorsement by the National Institute of Standards and Technology.

Description of the CSCW Systems

To support the described requirements and processes, we are using a combination of collaborative tools. To accelerate tool deployment, a survey of potential commercial and research tools was performed. None of the off-the-shelf tools available at that time provided all the required functionality. However we chose Teamwave Workplace[7] as the initial tool for deployment as it met many of the requirements, was extensible, and was developed in an environment supporting CSCW research. An ancillary tool supporting the replay and annotation of synchronized multimedia data streams is being developed in-house to support important data visualization requirements not supported with the native Teamwave Workplace toolkit. Descriptions of these systems follow.

The initial tool deployed was Teamwave Workplace, a rooms-based collaborative system with a whiteboard backdrop. Rooms provide boundaries for data groupings and user interactions and a metaphor for easing the transition in groupware (Greenberg et al., 1998). Data organization within rooms is configurable by its occupants in how they organize various tools housing their data, such as file viewers, file holders, PostIt™ notes, and message boards. The system provides for synchronous and asynchronous user interactions, but importantly, these interactions are in the context of relevant data. The tool set is extensible in that custom tools can be added. We have worked with the vendor to augment a special version of it to facilitate the logging of events for our analysis work. Figure 1 shows a screen shot of a room in Teamwave Workplace supporting the analysis activities of a test weld. The left-most portion of the room shows summary status and navigation information, the center portion shows data regarding a representative "good" weld and the right portion shows tools containing information for a "bad" weld. At the bottom of the window is an in-progress chat session regarding the analysis of the latest weld data.

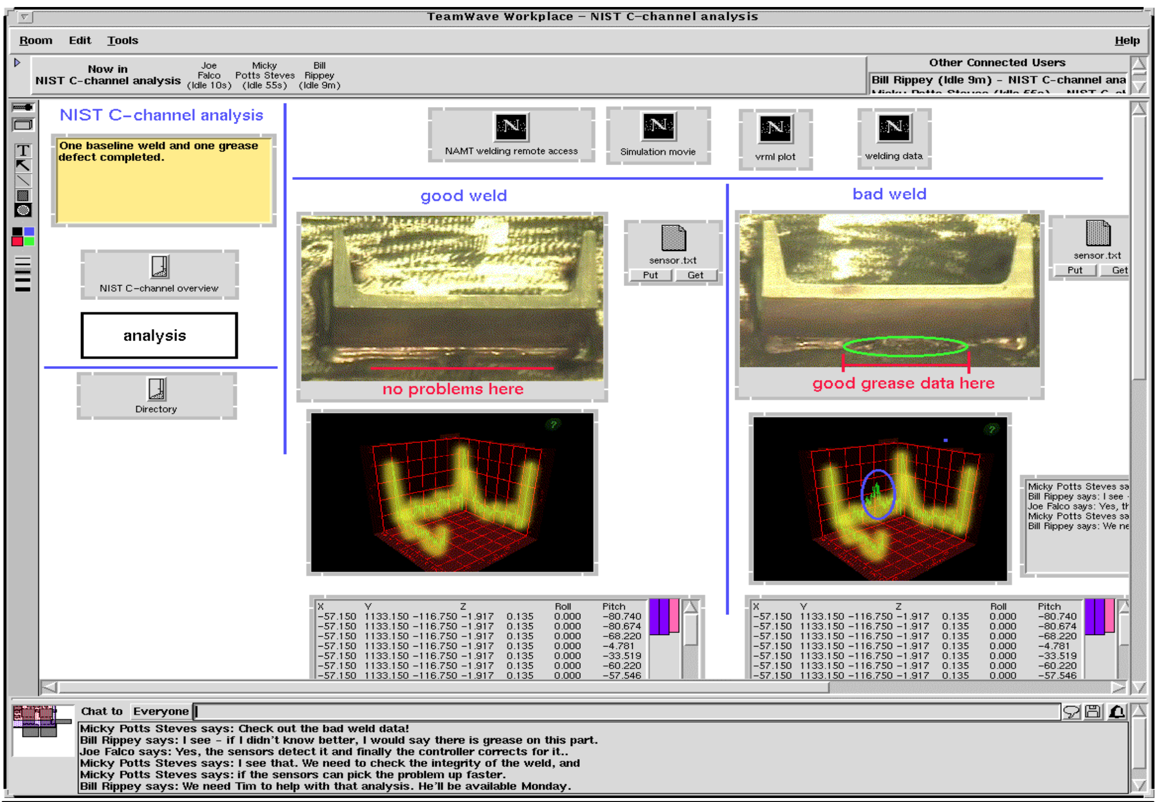

Figure 1: Teamwave Workplace with welding data

[7] Teamwave Workplace [Roseman 99] is a commercial product identified in this document for the purpose of evaluating a class of collaboration technologies. This identification does not imply any recommendation or endorsement by the National Institute of Standards and Technology.

Additionally, we are developing a weld data visualization tool, which provides synchronized multimedia playback of welding data with annotation capabilities to support weld analysis and trouble shooting. This tool provides capabilities to playback multiple synchronized welding data streams for review and annotation. The types of data we expect to support are sensor output (text), controller logs (text), audio, and possibly video. The sensor, controller, and audio will be indexed over the video data, a still photo of the completed weld or possibly over a VRML representation of the Computer Aided Design (CAD) data for the weld, if available. This tool will be integrated in the second round of deployment of Phase I. It is also expected that a version of this tool will be used in the operations environment, adapted to the "Jade" scenario described in the introductory section of this paper.

Data Collection Techniques and Tools

We are using a combination of user interviews, observation, monitoring of an email list for the NIST welding research team, and the collaboration tools' augmented log data. We are in the process of building a data visualization tool to help assess the log data; this is being built in-house because existing off-the-shelf visualization tools do not adequately represent timeline data for our purposes. The visualization shows room occupation, tool use for each user, and where synchronous and asynchronous use occurs over time (relative to log file events and clock time). We expect this data visualization tool will lessen the evaluation time required to identify and understand pertinent aspects and patterns of usage. We are particularly interested in discovering the rhythm of synchronous and asynchronous interactions (if any), what objects are used during interactions, if there are precursors to interactions (e.g., bell rings, pages), etc. We also plan to have the tool quantify general use trends such as where users (by role) tend to spend their time (room and tool usage), if users seem to prefer synchronous to asynchronous interactions or vice versa, etc. We should also be able to identify irregular use patterns from the visualization and discuss these observations with our users during the interview portion of the evaluation as well. Figure 2 depicts some sample visualizations of the log data[8], they are provided to give the reader a feel for the types of visualizations completed to date. The visualization on the left shows tool usage (all types) by users as they occupy different rooms. The visualization on the right shows a different view of tool usage by users as they occupy different rooms. All visualizations are on a time scale relative to other events in the log and have flexible zooming of those time scales.

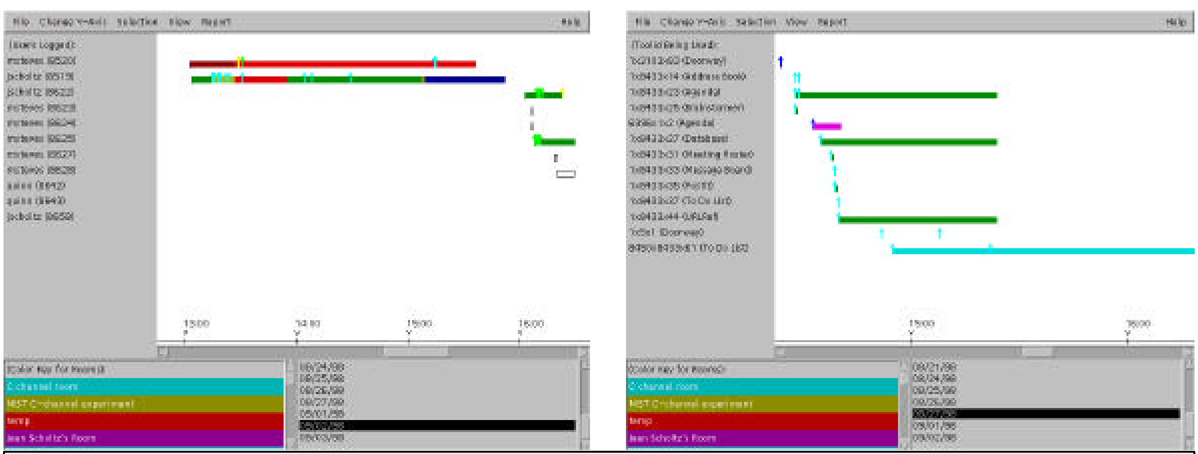

Figure 2: Sample log data visualizations

[8] Color is an integral part of these visualizations. Intrepretability is significantly diminished in non-color copies.

Evaluation Methodology

To support our evaluation goals, we are using a modified field study methodology. Using what we learn during the requirements gathering and process workflow documentation phases, we seed the CSCW system with relevant artifacts prior to its deployment for the users. To accomplish this, we populate a set of rooms with artifacts (tools containing real data) representing our understanding of the process workflow, relevant data, and anticipated collaboration points. Some initial training and/or demonstration of the system with this seeding will be performed with the users. This is being done with the intent to lessen the time it takes the users to understand and effectively use the system in their work environment. It is also expected that this seeding will be done in the operations environment. By using automated logs, we will be able to see how closely our initial work corresponds to how users use the system. We will be able to track the changes made to rooms as the welding team uses the software.

Initial Results

As depicted in the chart describing our progress, we are in the early phases of deployment and use analysis. Here are some preliminary observations.

1. There are strengths and weaknesses of the rooms-based metaphor that was used by our primary groupware system. Rooms are a good organizing principle. Our participants readily understood moving between rooms and creating new rooms for new groupings of data and interactions. The rooms are easier to populate than creating and maintaining web pages. However, there were times when we found the room boundaries to be rather heavyweight. For example, our users found it somewhat disruptive to change rooms, generally to review a different data set, during a synchronous collaboration. Additionally, the finite amount of screen space for a given room can be a limitation.

2. Users who had seen collaborative system used with welding artifacts better understood how to use the system than those who had no such familiarity. This was illustrated by the observations that there was a direct correlation between users' exposure to the tool prior to the actual user training session and ease of tool concept comprehension during training.

3. Another interesting discovery was a seeming contradiction with the WYSIWIS (what you see is what I see) model and the rooms metaphor. Initially, this model is comforting to users; they feel comfortable that while in the same room, they see what everyone else (in the same room) sees, can discern what is happening to artifacts in that room and who is affecting any changes. However, as rooms became populated with welding data, it became desirable to have particular artifacts replicated in multiple rooms. This raises a maintenance issue, for example, when a change is made to a replicated artifact in one room, there is no easy method for propagating the change to the other "duplicate" artifacts. However, allowing changes to be propagated would be a violation of the WYSIWIS model because, changes to "duplicate" artifacts would be affected by a non-resident of the artifact-housed room. This could possibly be avoided by the implementation of agents or proxies, which would enter rooms housing "duplicate" artifacts to affect the desired changes. These agents or proxies communication abilities would only extend to being able to relate whom (which real user) was directing the artifact change(s) and where they were located (which room) on the system.

These observations lead to some design implications for Teamwave Workplace and similar collaborative system tools.

1. The ability to iconify component tools would reduce the demands for screen real estate.
2. Storing meta-data about instances of component tools would be helpful for maintenance, e.g.,
    - who created this
    - when was it created, last modified, etc.
    - from which file system and from where in the file system did it come
3. Embedding tools in other tools is very useful, for example, for allowing dynamically updated tables.

Desired functionality includes:

- pointers to image viewers and web viewers that provide a shared view of data (e.g., photos, sensor plots, etc.)
- iconified versions of component tools

4. Relaxing the WYSIWIS model may be desirable for ease of maintenance.
   - objects allowed to appear in multiple rooms
   - updates to replicated objects are propagated to all associated artifacts
5. Special user-defined “template” rooms to make it easier to create new rooms with pre-defined characteristics and tools.
6. Good user interfaces to access and maintain data easily are a necessity.
7. Role-based access control is a relatively convenient and practical method for access control.
8. Secure transmission of data over the Internet is often desirable.
9. A programmable interface would allow “agents” to deposit data items in rooms and/or maintain data items as they change elsewhere.

Anticipated Results

1. With respect to deploying collaboration tools, we expect to determine the usefulness of:
   - The *seeding method*, i.e., where the groupware tools are seeded with task and workflow relevant artifacts prior to user training and deployment in an effort to decrease the amount of time necessary for users to gain proficiency and to increase user satisfaction with the tools.
   - *Accelerated deployment*, i.e., using an environment where the barriers and expenses are lower to gain experience (and therefore reduce the unknowns) about implementing groupware tools in environments where the barriers and expenses are greater.
2. In the welding research environment, we expect to show how these tools affect:
   - the time it takes to run a welding experiment and subsequent analysis
   - the quality of weld analysis
   - user-satisfaction regarding collaborations
3. In the welding operations environment, we expect to show:
   - how these tools affect trouble shooting welding problems
   - if these tools afford welding engineers better multiplexing of their time between problems
   - if operations and/or operations parameters change as a result of these tools (e.g., do welding workcells experience more up-time, does it take less welding engineer resources to manage a given number of workcells, etc.)

Future Research

This paper describes the research goals and initial results for this project. There remains a good deal of work to complete the planned research. As depicted in Table 1, future work in the welding research environment includes continuing the user-centered design method of cycling through 1) gathering and analyzing user requirements, 2) deploying tools and teaching users how to use them, and 3) analyzing tool use. We expect another two iterations of this cycle to be sufficient to provide effective tool deployment (given the current work process and user requirements), after which we will re-examine the welding experiment process to determine the impact of the groupware tools. In the near future, we expect to begin work in the operations environment with an industry partner, where the user-centered design method will also be employed.

Additionally, we believe that there is more work to be done in reducing the barriers to and the expenses of effective groupware and information technology systems deployment in the manufacturing domain. The *seeding* and *accelerated deployment methods* are two methods described in this paper, which need more research to show if they are generally useful in decreasing the amount of time necessary for users to gain tool proficiency, increasing satisfaction, and reducing the overall expense of groupware deployment.

Additionally, effective methods to document manufacturing processes and their changes must be identified for use.

In conclusion, the work described in this paper represents one scenario where collaboration technologies can be effectively used to improve the way manufacturers work in a distributed environment such as that arising from global manufacturing. Ultimately, the work presented here, in addition to similar systematic deployment and assessment of these types of tools in other manufacturing scenarios, will provide knowledge that is useful for manufacturers who wish to effectively employ and efficiently deploy collaboration technologies.

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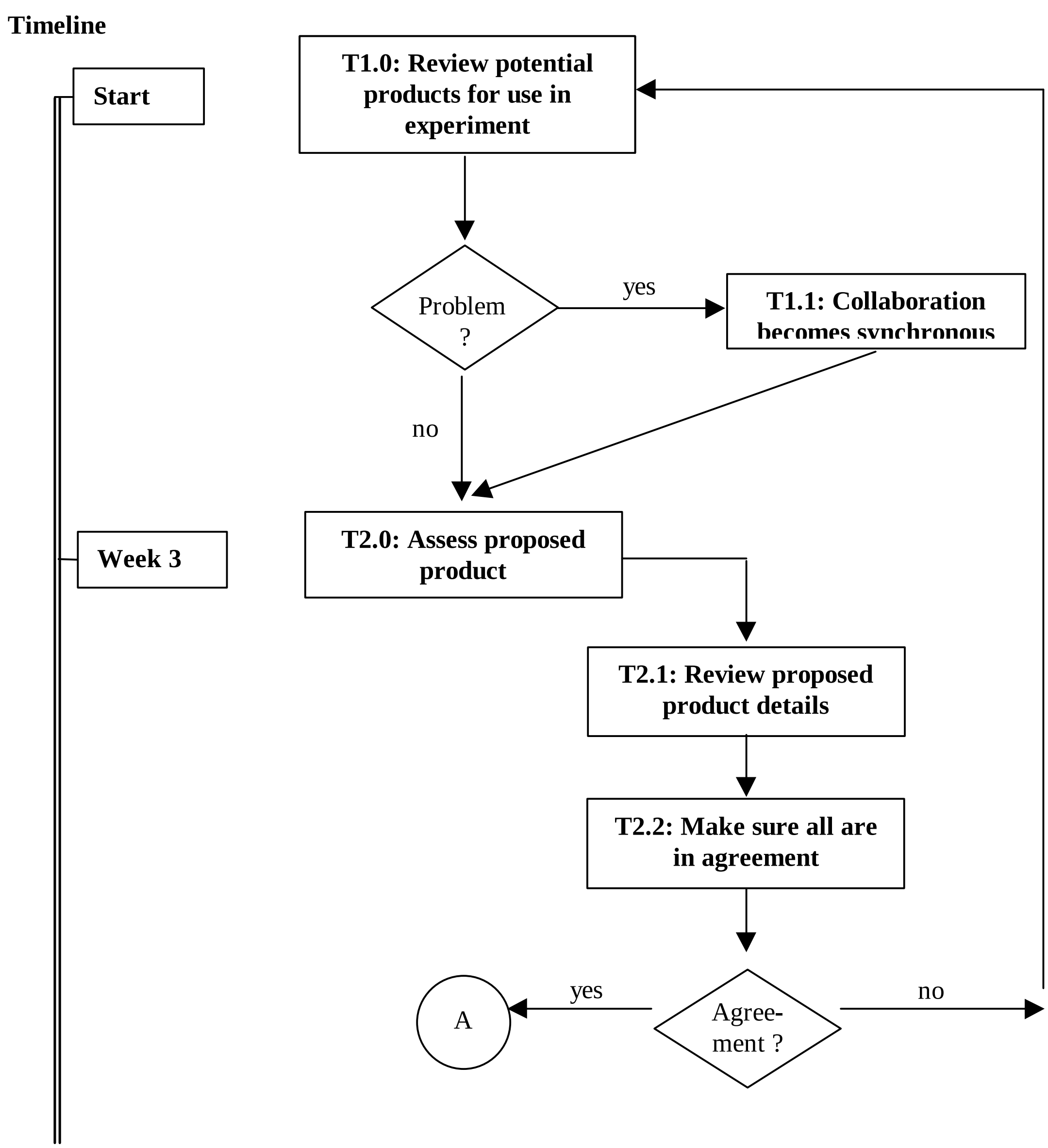
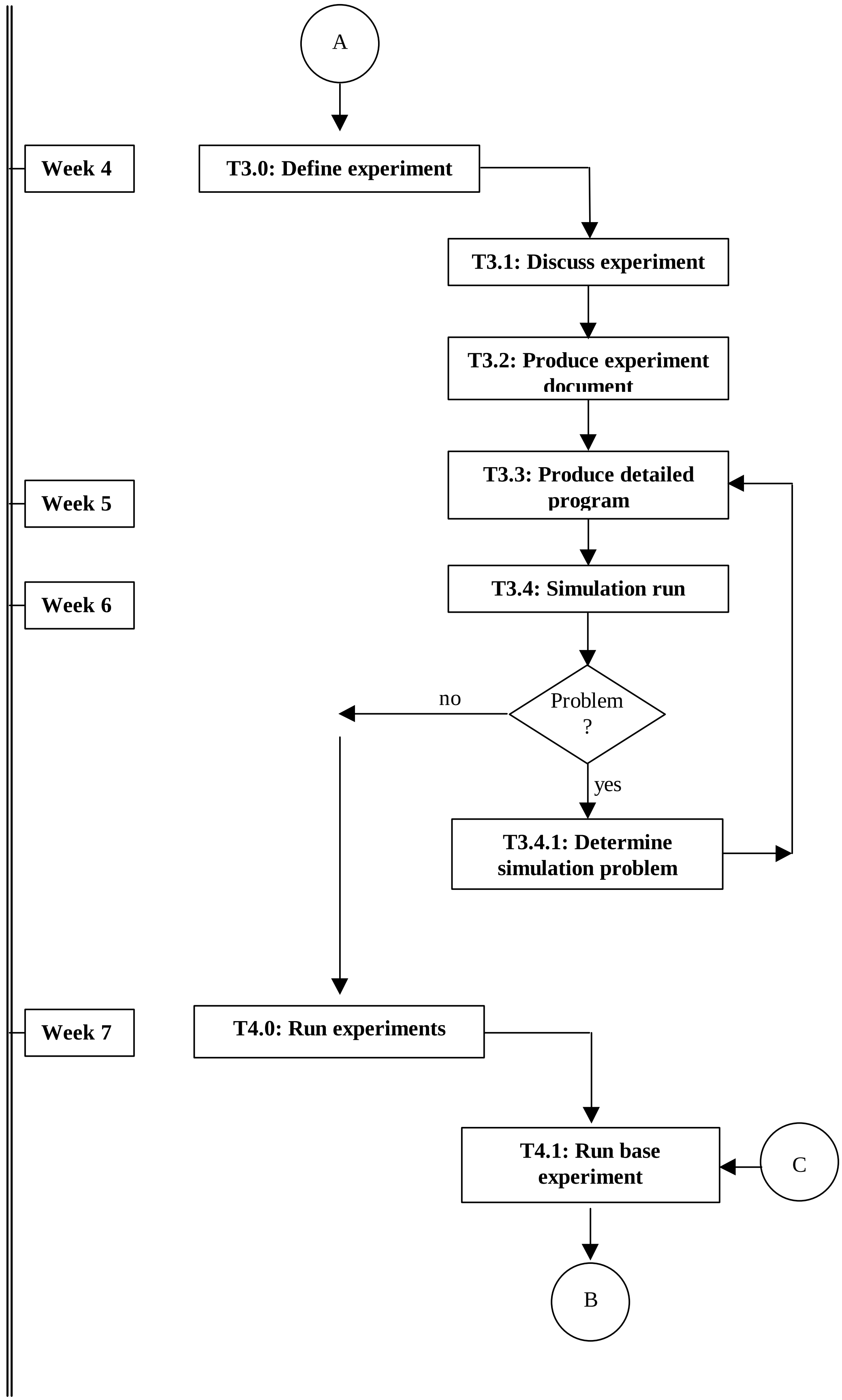
Appendix A: Detailed Representation of the Welding Process Analysis Scenario Processes and Timeline

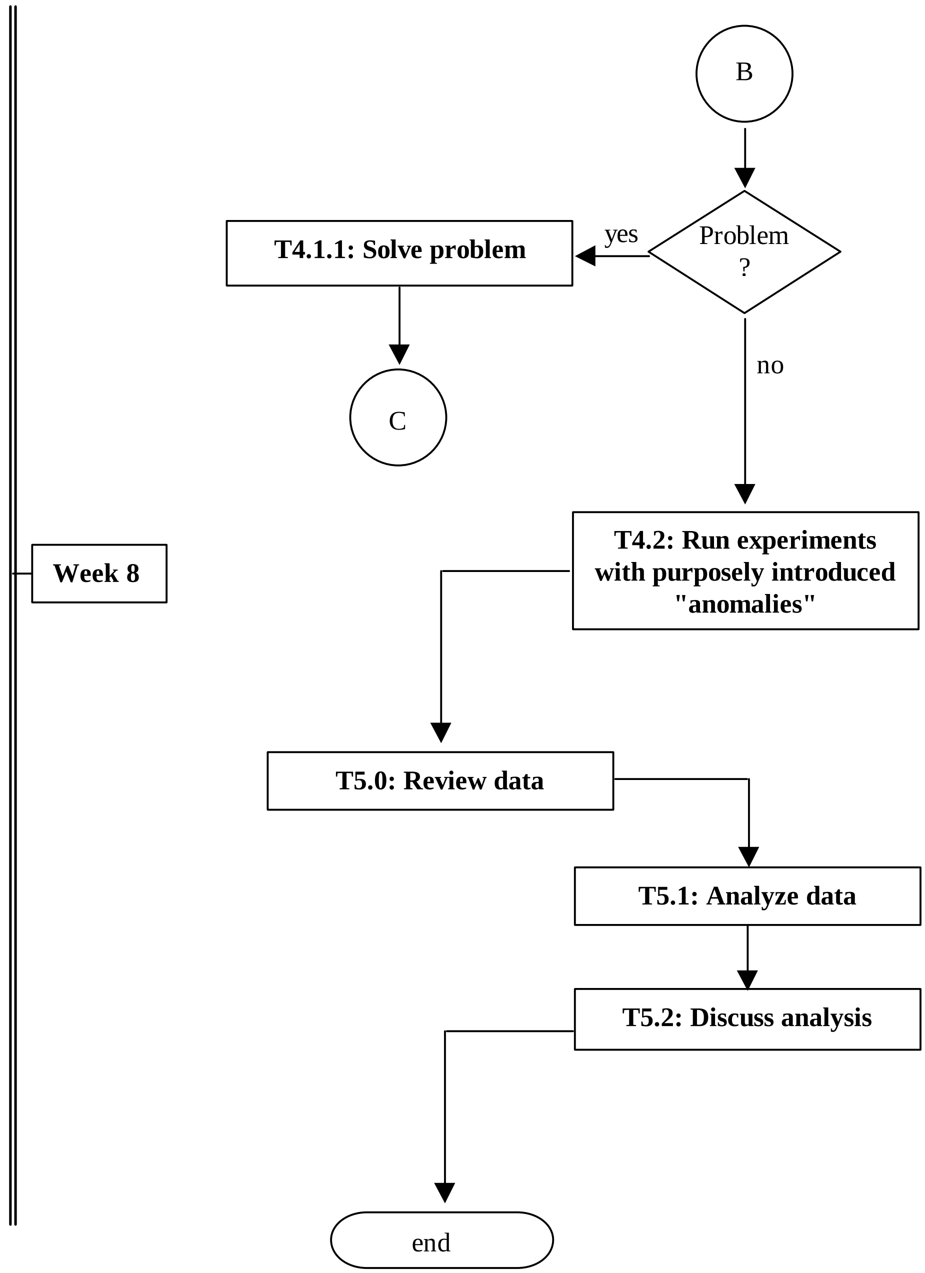
Description:

The following is a representation of the processes involved in the welding process analysis scenario, from product selection to final analysis of all variations of each weld for the selected product. The initial part of the representation uses a process flow chart in conjunction with a timeline to give an overview of the process flow. Each task is tagged with a numerical value. Major tasks are denoted by Tx.0 (Task, major activity number) representations, while subtasks are denoted by Tx.m[.n]. A timeline is depicted to the left of the flow chart with markers (in weeks) when tasks begin relative to the start of the assessment of a product's welds. The second portion of the process representation is a table that holds detailed information about each task, such as the collaborators, duration, collaboration mode and process inputs and outputs. Task tags are used to relate tasks between the flow chart and the table.

Flow Chart and Timeline:




A
Week 4
T3.0: Define experiment
T3.1: Discuss experiment
T3.2: Produce experiment document
Week 5
T3.3: Produce detailed program
Week 6
T3.4: Simulation run
no
Problem ?
yes
T3.4.1: Determine simulation problem
Week 7
T4.0: Run experiments
T4.1: Run base experiment
C
B



Activity Table

Activity	***Inputs***	***Outputs***
T1.0: Review potential products for use in experiment - Collaborators: product expert, manager, welding	1. Description of welding workcell configuration (read-only, text) 2. List of potential products	1. Proposed product selection 2. Comments on proposed product

Activity	*Inputs*	*Outputs*
engineer, algorithm expert - Duration: 2 weeks - 1 month - Collaboration mode: asynchronous**,** if no problems	(text) 3. For each potential product: - Product materials list (read-only, text) - Product weld procedures (read-only, text) - Product parameters, size, shapes, etc. (read-only, graphics) - Product description of welds, generally blueprints (read-only, graphics) - future enchancement: use/exchange of CAD drawing(s)	
T1.1: if problem arises during review, collaboration mode becomes synchronous	(T1.0 inputs)	(T1.0 outputs)
T2.0: Assess proposed product to see if it can be done mechanically and if it is an interesting process - Collaborators: sensor expert, cell programmer, algorithm expert - Duration: 3-7 days - Future enhancement: consult previous work to make sure that this work had not already been done	1. Description of NIST welding workcell configuration (read-only, text) 2. For proposed product: - Product materials list (read-only, text) - Product weld procedures (read-only, text) - Product parameters, size, shapes, etc. (read-only, graphics) - Product description of welds, generally blueprints (read-only, graphics) - Comments from selection process - future enchancement: CAD drawings 3. Future enhancement: Database of previous work (read-only)	
T2.1 Review proposed product details - Collaboration mode: asynchronous	(T2.0 inputs)	Each reviewer's assessment
T2.2: Make sure all are in agreement - Collaboration mode: synchronous	(T2.0 inputs)	Decision to proceed or return to Review Potential Products (T1.0)
T3.0: Define experiment		

Activity	*Inputs*	*Outputs*
T3.1 Discuss experiment - Collaborators: cell programmer, sensor expert, algorithm expert, test coordinator - Duration: 1 week - Collaboration mode: synchronous	(T2.0 inputs)	Discussion of experiment
T3.2: Produce experiment document - Performed by test coordinator - Duration: 0.5 weeks - Collaboration mode: stand-alone	(T2.0 inputs) + Discussion of experiment (T3.1 output)	Experiment document
T3.3: Produce detailed program - Performed by the cell programmer - Duration: 0.5 weeks - Collaboration mode: stand-alone	Experiment document (T3.2 output)	Detailed program
T3.4: Simulation run - Performed by the simulation expert - Duration: 1 week - Collaboration mode: stand-alone	Detailed program (T3.3 output)	VRML simulation model
T3.4.1: if problem arises during simulation run, collaboration mode becomes synchronous - Collaborators: simulation expert, sensor expert, algorithm expert, cell programmer	Detailed program (T3.3 output)	Modified detailed program
T4.0: Run experiments - Duration: 1 week + (time depends on number of tests run)	Detailed program (T3.3 output)	For each weld: 1. Sensor data 2. Welding cell data 3. Future enhancements: - Weld audio - Photo of finished weld
T4.1: Run base experiment - Performed by cell programmer	(T4.0 inputs)	(T4.0 outputs)
T4.1.1: if problem, discuss experiment and solve problem - Collaborators: sensor expert, cell programmer, algorithm expert, test coordinator	(T4.0 outputs)	Discussion of problem and solution(s)

Activity	*Inputs*	*Outputs*
- Collaboration mode: synchronous		
T4.2: Run experiments with purposely introduced "anomalies"	(T4.0 inputs + any modifications from T4.1.1)	(T4.0 outputs)
T5.0: Data review - Collaborators: algorithm expert, sensor expert, weld expert - Duration: dependent on number of tests run	(T4.0 outputs)	Expert comments and annotations
T5.1: Data analysis Collaboration mode: asynchronous	(T4.0 outputs)	(T5.0 outputs)
T5.2: Discuss analysis Collaboration mode: synchronous	(T4.0 outputs)	(T5.0 outputs) + discussion